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MACHINING DATA FOR NUMERICAL CONTROL

REAMING - AFMDC 66-1.7

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NOVEMBER 1966

Advanced Fabrication Techniques Branch
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AFMDC 65-2	FIRST ANNUAL REPORT OF THE AIR FORCE MACHINABILITY DATA CENTER, FEBRUARY 1966, AD-482 278
AFMDC 66-1.1	MACHINING DATA FOR NUMERICAL CONTROL - TURNING, JUNE 1966, AD-483 994
AFMDC 66-1.2	MACHINING DATA FOR NUMERICAL CONTROL - FACE MILLING, AUGUST 1966, AD-487 156
AFMDC 66-1.3	MACHINING DATA FOR NUMERICAL CONTROL - DRILLING, AUGUST 1966, AD-488 018
AFMDC 66-1.4	MACHINING DATA FOR NUMERICAL CONTROL - PERIPHERAL END MILLING, SEPTEMBER 1966
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AFMDC 66-1.7	MACHINING DATA FOR NUMERICAL CONTROL - REAMING, NOVEMBER 1966
AFMDC 66-2	GRINDING RATIOS FOR AEROSPACE ALLOYS, JUNE 1966, AD-483 995
AFMDC 66-3	MACHINING DATA FOR BERYLLIUM METAL, JUNE 1966, AD-485 297

DATA PRODUCTS IN PREPARATION:

AFMDC 66-1	MACHINING DATA FOR NUMERICAL CONTROL (COLLECTION OF 66-1.1 THROUGH 66-1.7 IN ONE VOLUME)

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APPENDIX

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INTRODUCTION

This report presents an extensive set of machining data selected from six USAF Machinability Reports. Data are tabulated and arranged in formats including all pertinent machining variables. The relationship between tool life and cutting speed is expressed in at least three sets of data, thereby making it possible to optimize for maximum production or minimum cost. While these data are expected to be of considerable assistance in providing data for numerical control applications, they are also of great value in any type of machining situation involving the materials for which machining data are presented. Specifically this report, No. 66-1.7, the final of this series, pertains to reaming. The preceding reports in this series were: turning, No. 66-1.1; face milling, No. 66-1.2; drilling, No. 66-1.3; peripheral end milling, No. 66-1.4; end mill slotting, No. 66-1.5; and tapping, No. 66-1.6.

Each report is distributed upon completion, and all reports for the various machining operations will be collected in a single volume, No. 66-1.

Numerical machining data in the aforementioned six USAF Machinability Reports are scattered among descriptive material. In order to make these data more readily available, they were extracted and rearranged in tabular formats. The condition, microstructure, and hardness of each material are indicated. All the significant data for machining a given work material are presented in one horizontal line. This includes the tool material, tool geometry, cutting fluid, depth, width of cut, feed, tool life end point, and then the reamer life vs. cutting speed relationships. Thus, by scanning across a single line, one can obtain all pertinent machining data covering an actual test.

All the actual test data carried out on each work material are included. The test data were developed under closely simulated conditions which permit their direct application in the machining industry. The tool life end point referenced in the data sheets is a measure of the flank tool wear. Data are shown for high speed steel tools, cast alloy tools, and various grades of carbide tools. By scanning the lines of data for any specific work material, one can visually determine the relative tool life-cutting speed relationships for tool materials including tool geometry, feeds, and cutting fluids.

For any specific work material in a heat treated form and hardness, the recommended starting conditions are also given. The Recommended Starting Cutting Speed is indicated by the letter "R" for a given work material, and the line on which the "R" appears gives a resumé of the cutting parameters as well as the tool life. This recommended speed and its accompanying cutting conditions are <u>not</u> necessarily the optimum but rather serve to provide the user with suggested conditions which will give satisfactory tool life under normal shop conditions.

The <u>optimum</u> cutting parameters for machining a given work material on a given machine tool can be determined by obtaining tool life-speed, feed and cutting parameter relationships, and then using these data to calculate the cost and production rate for the various cutting parameter combinations. The optimum condition is that which produces minimum cost or maximum production. The machining test data which we present in this report are well suited for calculating optimum costs and production rates. This can be done by placing these actual machining test data into a computer which has been programmed to calculate costs and production rates. The computer output can be examined either graphically or in tabular form to ascertain the minimum cost or maximum production. N/C programmers need specific machining data in a form suitable for rapid and accurate inclusion in their machine tool programs. The data presented herein can either be scanned visually or computer optimized for this purpose. Any further questions regarding optimization should be directed as specific inquiries to the Air Force Machinability Data Center.

Supplementary data and information which will be useful for ready reference purposes are included in the Appendix, pages A-2 through A-18.

The six volumes from which these machining data were collected are:

ITEM		SUMMARY OF CONTENT
1	USAF Machinability Report, Vol. 1, (1950)	Machining fundamentals and machining data on high temperature alloys.
2	USAF Machinability Report, Vol. 2, (1951)	Turning data on 12 steels in various microstructural forms.
3	USAF Machinability Report, Vol. 3, (1954)	Machining of titanium alloys including turning, milling, drilling, tapping, and grinding data.
4	USAF Machinability Report, Vol. 4, (1960)	Machining of thermal resistant and high strength steels using a variety of important machining operations.
5	"Final Report on Machining of Refractory Materials", ASD-TDR-63-581, July 1963	Machining data on alloys of columbium, molybdenum, tungsten, tantalum and important high temperature alloys and nonmetallic materials; Tornetic drilling and tapping, high speed milling.
6	"Final Report on Machinability of Materials", AFML-TR-65-444, January 1966	Machining data on ultra-high strength steels, titanium alloys, and nickel and cobalt base high temperature alloys. A section is included on evaluation of Surface Integrity in machined and ground aerospace alloys.

NOTES:

1. *Volumes 1 and 2, USAF Machinability Reports, are out of print but may possibly be obtained from libraries or on loan from AFMDC for a reasonable time or for reproduction.*

2. *A limited number of Volumes 3 and 4, USAF Machinability Reports, may be obtained from AFMDC without charge by providing information on specific needs for machining data on titanium, high strength steels, and high temperature alloys.*

3. *"Final Report on Machining of Refractory Materials", and "Final Report on Machinability of Materials" may also be obtained from AFMDC by providing need-to-know justification for the materials covered in each report (see description of content in Items 5 and 6 above).*

REAMING

REAMING - INDEX TO DATA TABLES

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	CHAMFER	REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R=Recommended Speed Appendix Page A-2				
ULTRA-HIGH STRENGTH STEELS																				
D6AC	QUENCHED & TEMPERED	$56R_c$	883	C-2	.272	4	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.001	.012	5	15	25	15	4
	TEMPERED MARTENSITE							RH								100	80	60	50	40
"	"	"	"	"	"	"	CHUCKING -5° x .010" HONED ON CORNERS	"	"	"	"	"	"	.002	"	20	47	60	35	15
	"							"								115	85	65 R	47	35
"	"	"	"	"	"	"	CHUCKING	"	"	"	"	"	"	"	"			5		
	"							"										65		
D6AC	QUENCHED & TEMPERED	$56R_c$	883	C-2	.272	4	CHUCKING -5° x .010" HONED ON CORNERS	0°	45° x .060"	10	53	.020	.5 THRU	.002	.012			60		
	TEMPERED MARTENSITE							RH										65		
D6AC	QUENCHED & TEMPERED	$56R_c$	883	C-2	.272	4	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.002	.012			60		
	TEMPERED MARTENSITE							RH										65		
"	"	"	"	"	"	"	"	"	"	"	11 1:20	"	"	"	"			30		
	"							"										65		
250 GRADE MARAGING STEEL	ANNEALED	321	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.009	.006	40	123	170		
	MARTENSITE							RH								200	175	160 R		
"	"	"	-	"	"	"	"	"	"	"	53	"	"	"	"	13	85	190		
	"							"								200	175	150		
"	"	"	-	"	"	"	"	"	"	"	11 1:20	"	"	"	"	35	40	68		
	"							"								150	100	85		

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R-Recommended Speed Appendix Page A-2				
ULTRA-HIGH STRENGTH STEELS - *(cont.)*																				
250 GRADE MARAGING STEEL	ANNEALED & MARAGED	50R$_c$	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.005	.006	20	35	170		
	MARTENSITE							RH								90	80	50		
"	"	"	-	M33 HSS	"	"	"	"	"	"	"	"	"	"	"	20	60	90		
	"							"								130	110	100 R		
"	"	"	-	M2 HSS	"	"	"	"	"	"	53	"	"	"	"	30	50	175		
	"							"								65	45	27		
250 GRADE MARAGING STEEL	ANNEALED & MARAGED	50R$_c$	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.005	.006	170				
	MARTENSITE							RH								50				
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.009	"	120				
	"							"								50				
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.015	"	70				
	"							"								50				
300 GRADE MARAGING STEEL	ANNEALED	348	-	M1 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.009	.006	65	120	300		
	MARTENSITE							RH								125	113	75 R		
"	"	"	-	"	"	"	"	"	"	"	53	"	"	"	"	80	100	160		
	"							"								125	113	100		
"	"	"	-	"	"	"	"	"	"	"	11 1:20	"	"	"	"	35	60			
	"							"								125	100			

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R=Recommended Speed Appendix Page A-2				
ULTRA-HIGH STRENGTH STEELS - *(cont.)*																				
300 GRADE MARAGING STEEL	ANNEALED & MARAGED	$52R_c$	-	M33 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.005	.006	35	37	45	85	
	MARTENSITE							RH								75	60	50	40	
"	"	"	-	M2 HSS	"	"	"	"	"	"	53	"	"	"	"	40	60	120		
	"							"								55	45	35 R		
"	"	"	-	"	"	"	"	"	"	"	52	"	"	"	"	16	70	140		
	"							"								40	30	25		
300 GRADE MARAGING STEEL	ANNEALED & MARAGED	$52R_c$	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.005	.006			140		
	MARTENSITE							RH										25		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.009	"			85		
	"							"										25		
300 GRADE MARAGING STEEL	ANNEALED & MARAGED	$52R_c$	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.005	.006		70			
	MARTENSITE							RH									30			
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.009	"		40			
	"							"									30			
HP 9-4-25	ANNEALED	341	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.009	.006	15	58	145		
	SPHEROIDIZED							RH								140	125	110 R		
"	"	"	-	"	"	"	"	"	"	"	11 1:20	"	"	"	"	27	62	120		
	"							"								125	110	100		

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R-Recommended Speed Appendix Page A-2				
TITANIUM ALLOYS																				
TI-8AL-1MO-1V	ANNEALED	302	-	M2 HSS	.272	6	CHUCKING	0°	45° X .060"	7	53	.022	.5 THRU	.009	.006	15	120	300		
	ALPHA							RH								90	80	70		
"	"	"	-	"	"	"	"	"	"	"	83	"	"	"	"	5	105	200		
	"							"								80	70	65 R		
"	"	"	-	"	"	"	"	"	"	"	11 1:20	"	"	"	"	10	65	300		
	"							"								70	65	60		
TI-3AL-13V-11CR	SOLUTION TREATED & AGED	400	-	M1 HSS	.272	6	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.001	.015	8	37	65	75	
	BETA							RH								70	50	40	30	
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.002	"	2	35	95		
	"							"								70	50	30		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.005	"	6	80	185		
	"							"								70	50	30 R		
HIGH TEMPERATURE ALLOYS - NICKEL BASE WROUGHT -																				
INCONEL 718	SOLUTION TREATED	245	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	7	52	.022	.5 THRU	.005	.006	5	8			
	AUSTENITIC							RH								50	20			
"	"	"	883	C-2	"	4	"	"	"	"	"	"	"	.009	"	35	75			
	"							"								90	70 R			

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R=Recommended Speed Appendix Page A-2				
HIGH TEMPERATURE ALLOYS - NICKEL BASE WROUGHT - (cont.) WASPALOY	SOLUTION TREATED AUSTENITIC	293	-	M2 HSS	.272	6	CHUCKING	0° RH	45° x .060"	7	52	.022	.5 THRU	.002	.006	45 45				
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.005	"	80 45				
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.009	"	80 45 R				
WASPALOY	SOLUTION TREATED AUSTENITIC	293	-	M2 HSS	.272	6	CHUCKING	0° RH	45° x .060"	7	52	.022	.5 THRU	.002	.006	15 50				
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.005	"	60 50				
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.009	"	10 50				
RENE' 41	SOLUTION TREATED AUSTENITIC	321	-	M2 HSS	.272	6	CHUCKING	0° RH	45° x .060"	10	53	.020	.5 THRU	.005	.016	22 30	95 25 R	72 20	65 17	
"	" "	"	-	"	"	"	"	" "	"	"	52	"	"	"	"			30 20		
"	" "	"	-	"	"	"	"	" "	"	"	11 1:10	"	"	"	"			8 20		

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R-Recommended Speed Appendix Page A-2				
HIGH TEMPERATURE ALLOYS - NICKEL BASE WROUGHT - (cont.) RENE' 41	SOLUTION TREATED	321	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.005	.016			72		
	AUSTENITIC							RH										20		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.009	"			32		
	"							"										20		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.015	"			7		
	"							"										20		
RENE' 41	SOLUTION TREATED & AGED	365	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.005	.016	8	40	94	70	
	AUSTENITIC							RH								30	25	20 R	17	
"	"	"	-	"	"	"	"	"	"	"	52	"	"	"	"				45	
	"							"											17	
"	"	"	-	"	"	"	"	"	"	"	11 1:20	"	"	"	"				21	
	"							"											17	
RENE' 41	SOLUTION TREATED & AGED	365	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.005	.016			94		
	AUSTENITIC							RH										20		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.009	"			35		
	"							"										20		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.015	"			15		
	"							"										20		

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	CHAMFER	REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R=Recommended Speed Appendix Page A-2				
REFRACTORY ALLOYS - MOLYBDENUM ALLOYS																				
MOLY-TZM	EXTRUDED	229	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	10	53	.020	.5 THRU	.009	.012	20	36	45		
	ELONGATED GRAINS							RH								105	85	62 R		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.015	"	22	40	52		
	"							"								105	85	62		
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.020	"			25		
	"							"										62		
MOLY-TZM	EXTRUDED	229	-	M2 HSS	.272	6	CHUCKING	0°	45° x .060"	10	11 1:20	.020	.5 THRU	.015	.012		15			
	ELONGATED GRAINS							RH									85			
"	"	"	-	"	"	"	"	"	"	"	52	"	"	"	"		30			
	"							"									85			
"	"	"	-	"	"	"	"	"	"	"	53	"	"	"	"		40			
	"							"									85			
MOLY-0.5% TI	STRESS RELIEVED	220	-	M2 HSS	.213	6	CHUCKING	10°	45° x .060"	10	53	.020	.5 THRU	.007	.010		25			
	ELONGATED GRAINS							RH									85			
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.011	"		35			
	"							"									85			
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.015	"		45			
	"							"									85 R			
"	"	"	-	"	"	"	"	"	"	"	"	"	"	.020	"		60			
	"							"									85			

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R-Recommended Speed Appendix Page A-2				
REFRACTORY ALLOYS - MOLYBDENUM ALLOYS (cont.)																				
MOLY-0.5% Ti	STRESS RELIEVED	220	-	M2 HSS	.213	6	CHUCKING	10°	45° x .060"	10	53	.020	.5 THRU	.009	.010	27				
	ELONGATED GRAINS							RH								64				
"	"	"	-	"	"	"	"	0°	"	"	"	"	"	"	"	23				
	"							RH								64				
"	"	"	-	"	"	"	"	10°	"	"	"	"	"	"	"	30				
	"							LH								64				
MOLY-0.5% Ti	STRESS RELIEVED	220	-	M2 HSS	.213	6	CHUCKING	10°	45° x .060"	10	11 1:20	.020	.5 THRU	.020	.010	25				
	ELONGATED GRAINS							RH								85				
"	"	"	-	"	"	"	"	"	"	"	52	"	"	"	"	59				
	"							"								85				
"	"	"	-	"	"	"	"	"	"	"	53	"	"	"	"	60				
	"							"								85				
REFRACTORY ALLOYS - COLUMBIUM ALLOYS																				
D-31	EXTRUDED & STRESS RELIEVED	207	-	M2 HSS	.213	6	CHUCKING	10°	45° x .060"	10	52	.020	.5 THRU	.005	.012	25	40	54	103	
	ELONGATED GRAINS							RH								175	162	150	125 R	
"	"	"	-	"	"	"	"	"	"	"	53	"	"	"	"			12		
	"							"										150		
"	"	"	-	"	"	"	"	"	"	"	11 1:20	"	"	"	"				14	
	"							"											125	
"	"	"	-	"	"	"	"	0°	"	"	52	"	"	"	"			20		
	"							RH										150		

REAMING

MATERIAL	CONDITION & MICROSTRUCTURE	BHN	REAMER DESCRIPTION: TOOL MATL. TRADE NAME	REAMER DESCRIPTION: TOOL MATL. INDUSTRY GRADE	DIA. in.	NO. OF FLUTES	STYLE	TOOL GEOMETRY: HELIX & HAND	TOOL GEOMETRY: CHAMFER	TOOL GEOMETRY: REL°	CUTTING FLUID Appendix p. A-2	STOCK ALLOW. ON DIA. in.	LENGTH OF HOLE in.	FEED ipr	TOOL LIFE END POINT in.	REAMER LIFE NO. OF HOLES vs SPEED-feet/minute R=Recommended Speed Appendix Page A-2				
REFRACTORY ALLOYS - COLUMBIUM ALLOYS (cont.) D-31	EXTRUDED & STRESS RELIEVED ELONGATED GRAINS	207	-	M2 HSS	.213	6	CHUCKING	10° RH	45° x .060"	10	52	.020	.5 THRU	.002	.012			33 150		
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.005	"			54 150		
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.009	"			12 150		
REFRACTORY ALLOYS - TANTALUM ALLOYS 90TA-10W	AS FORGED EQUIAXED GRAINS	207	-	M2 HSS	.213	6	CHUCKING	10° RH	45° x .060"	10	53	.020	.5 THRU	.005	.012			30 75		
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.009	"	14 100	67 85	64 75 R	42 50	
"	" "	"	-	"	"	"	"	" "	"	"	"	"	"	.015	"			5 75		
90TA-10W	AS FORGED EQUIAXED GRAINS	207	-	M2 HSS	.213	6	CHUCKING	10° RH	45° x .060"	10	52	.020	.5 THRU	.009	.012			2 75		
"	" "	"	-	"	"	"	"	" "	"	"	11 1:20	"	"	"	"			4 75		
"	" "	"	-	"	"	"	"	" "	"	"	53	"	"	"	"			62 75		

APPENDIX

CUTTING FLUIDS USED IN TESTS

CODE NO.	DESCRIPTION
00	None, Dry
11	Water soluble oil - light duty
13	Heavy duty soluble oil
21	Chemical emulsion
31	Sulfurized mineral lard oil - light duty
52	Sulfo-chlorinated mineral lard oil - medium duty
53	Highly chlorinated mineral oil - heavy duty
54	Heavy duty highly chlorinated cutting oil
83	Ti-Kut Oil (especially for titanium)
mc	Mist through cutter

Solution Concentrations:

1:10 denotes one part of concentrate to 10 parts of water by volume

1:15 denotes one part of concentrate to 15 parts of water by volume

1:20 denotes one part of concentrate to 20 parts of water by volume

1:25 denotes one part of concentrate to 25 parts of water by volume

R = RECOMMENDED CUTTING SPEED

The Recommended Starting Cutting Speed is indicated by the letter "R" for a given work material, and the line on which the "R" appears gives a resume of the cutting parameters as well as the tool life. This recommended speed and its accompanying cutting conditions are not necessarily the optimum but rather serve to provide the user with suggested conditions which will give satisfactory tool life under normal shop conditions. To take full advantage of the data presented, it will be necessary to optimize; i.e. to determine maximum production and minimum cost. (See general comments on optimizing in the Introduction and/or direct specific inquiries concerning optimization to the Air Force Machinability Data Center.)

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CARBIDE GRADE CHART

C-1 to C-8
MACHINING APPLICATIONS

CARBIDE MANUFACTURERS	INDUSTRY CODE							
	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
ADAMAS	B	A AM PWX	PWX AA	AAA	DD 5X 434	6X D	7X C 548 Titan 80*	CC Titan 80*
AMCARB	--	D15 D13	--	--	--	--	--	--
BESLY-WELLES	B101	B106 B166	B108	B211	B109 B221	B102	B103 B104 B205 B245	B207 B365*
CARBOLOY	44A	883 860	883 905 895	999 895 320	370 78B	370 78B 78 350	350 78 320	320
CARMET	CA-3	CA-4 CA-443	CA-7	CA-8	CA-610 CA-740	CA-608 CA-720	CA-711	CA-704
COROMANT	H20	H13 H20 H1P	H1P	H05	S6 S4	S2	S1P	F02*
FIRTH-LOACH	FA-5	FA-6	FA-7	FA-8	FT-3 FT-4 FT-5	FT-5 FT-62	FT-6 FT-62	FT-7 FT-72*
FIRTH STERLING	H	HA H-23	HE	HF	T04 NTA	TXH T22	T22 TXL	T31 WF*
FUTURMILL	--	DMC21	--	--	DMC30 DMC32	DMC32	DMC35	--
KENNAMETAL	K1	K6 C8735 K68	K68 K8	K11	KM K21 K2S	K2S K3H K4H K45	K45 K5H K7H	K7H K165*
MULTI METALS	OM1	OM2	OM3	OM4	4M5	--	--	--
NEWCOMER	N10	N20	N30	N40	N50	N60	N70 NM-93*	N80 NM-93* NM-95*
SINTERCAST	Ferro-Tic J	Ferro-Tic J	--	--	Ferro-Tic J	Ferro-Tic J	--	--
SPEEDICUT MITIA	A	B	C	C	TA10 TA5	TTA	TE	TE
TALIDE	C-89	C-91	C-93	C-95	S-880	S-901	S-92 S-900	S-94
TUNGSTEN ALLOY	9	9H	9C	9B	11T 9S 10T	9S 10T 5S	6T 5S	5S
UNIMET	U10	U20	U30	U40	U53	U53 U60	U70 U73	U73 U80 U88*
VALENITE	VC-1	VC-2 VC-22 VC-28	VC-3	VC-4	VC-125 VC-55	VC-125 VC-6	VC-7	VC-8 VC-83* VC-85*
VR/WESSON	2A-68 VR-54	2A-5 VR-54	2A-7	VR-52 2A-7 VR-65*	WS VR-77 VR-89 VR-75	VR-75 WM	VR-73 WH HV VR-65*	HV VR-73 VR-65*
WALMET	WA-141 WA-1 WA-159	WA-2 WA-63 WA-149	WA-35 WA-3	WA-4	WA-66 WA-5	WA-5 WA-6	WA-147 WA-7	WA-8
WENDT-SONIS	CQ12	CQ2	CQ3	CQ4	CY12 CY16	CY16 CY5	CY14 CY2 T18*	CY31 T18*
WICKALOY	N	H	HH	HHH	X7A X7	88	GX	FX
WILLEY'S	E8	E6	E5	E3	945 8A 10A	8A	606 6A	6AX 509

CAST IRON, NON-FERROUS AND NON-METALLIC MATERIALS

- C-1 Roughing
- C-2 General Purpose
- C-3 Finishing
- C-4 Precision Finishing

STEEL AND STEEL ALLOYS

- C-5 Roughing
- C-6 General Purpose
- C-7 Finishing
- C-8 Precision Finishing

Listings do not necessarily imply equivalency of various manufacturer's grades.
This chart is not to be considered an endorsement of or an approved list of any manufacturer's products.
Grades containing more than 50% Titanium Carbide.

IDENTIFICATION AND TYPE CLASSIFICATION OF HIGH SPEED TOOL STEELS

SYMBOL M, MOLYBDENUM TYPES							
TYPE	IDENTIFYING ELEMENTS, IN PER CENT						APPLICATION
	C	W	Mo	Cr	V	Co	
M1	.80	1.50	8.00	4.00	1.00	-	GENERAL PURPOSE
M2	.85	6.00	5.00	4.00	2.00	-	GENERAL PURPOSE
M3 CLASS 1	1.05	6.00	5.00	4.00	2.40	-	FINE EDGE TOOLS
M3 CLASS 2	1.20	6.00	5.00	4.00	3.00	-	FINE EDGE TOOLS
M4	1.30	5.50	4.50	4.00	4.00	-	ABRASION RESISTANT
M6	.80	4.00	5.00	4.00	1.50	12.00	HEAVY CUTS - ABRASION RESISTANT
M7	1.00	1.75	8.75	4.00	2.00	-	FINE EDGE TOOLS - ABRASION RESISTANT
M10	.90	-	8.00	4.00	2.00	-	GENERAL PURPOSE - HIGH STRENGTH
M15	1.50	6.50	3.50	4.00	5.00	5.00	HEAVY CUTS - ABRASION RESISTANT
M30	.80	2.00	8.00	4.00	1.25	5.00	HEAVY CUTS - ABRASION RESISTANT
M33	.90	1.50	9.50	4.00	1.15	8.00	HEAVY CUTS - ABRASION RESISTANT
M34	.90	2.00	8.00	4.00	2.00	8.00	HEAVY CUTS - ABRASION RESISTANT
M35	.80	6.00	5.00	4.00	2.00	5.00	HEAVY CUTS - ABRASION RESISTANT
M36	.80	6.00	5.00	4.00	2.00	8.00	HEAVY CUTS - ABRASION RESISTANT
M41	1.10	6.75	3.75	4.25	2.00	5.00	HEAVY CUTS - ABRASION RESISTANT
M42	1.10	1.50	9.50	3.75	1.15	8.00	HEAVY CUTS - ABRASION RESISTANT
M43	1.25	1.75	8.75	3.75	2.00	8.25	HEAVY CUTS - ABRASION RESISTANT
M44	1.15	5.25	6.25	4.25	2.25	12.00	HEAVY CUTS - ABRASION RESISTANT
SYMBOL T, TUNGSTEN TYPES							
T1	.70	18.00	-	4.00	1.00	-	GENERAL PURPOSE
T2	.80	18.00	-	4.00	2.00	-	GENERAL PURPOSE - HIGHER STRENGTH
T4	.75	18.00	-	4.00	1.00	5.00	HEAVY CUTS
T5	.80	18.00	-	4.00	2.00	8.00	HEAVY CUTS - ABRASION RESISTANT
T6	.80	20.00	-	4.50	1.50	12.00	HEAVY CUTS - HARD MATERIAL
T7	.75	14.00	-	4.00	2.00	-	PLANER TOOLS
T8	.75	14.00	-	4.00	2.00	5.00	GENERAL PURPOSE - HARD MATERIAL
T9	1.20	18.00	-	4.00	4.00	-	EXTREME ABRASION RESISTANT
T15	1.50	12.00	-	4.00	5.00	5.00	EXTREME ABRASION RESISTANT

GENERALLY ALL OF THE ABOVE HIGH SPEED STEELS ARE MANUFACTURED BY THE FOLLOWING COMPANIES:

- ALLEGHENY LUDLUM STEEL CORPORATION
- BETHLEHEM STEEL CORPORATION
- BRAEBURN ALLOY STEEL DIVISION, CONTINENTAL COPPER & STEEL INDUSTRIES, INC.
- THE CARPENTER STEEL COMPANY
- COLUMBIA TOOL STEEL COMPANY
- CRUCIBLE STEEL COMPANY OF AMERICA
- FIRTH STERLING, INC.
- JESSOP STEEL COMPANY
- LATROBE STEEL COMPANY
- H. K. PORTER COMPANY, INC., VULCAN-KIDD STEEL DIVISION
- SIMONDS SAW AND STEEL COMPANY
- UNIVERSAL-CYCLOPS STEEL CORPORATION
- VANADIUM-ALLOYS STEEL COMPANY, DIVISION OF VASCO METALS CORPORATION

HIGH SPEED STEELS M41 THROUGH M44 ARE MADE BY:

- M41 - CRUCIBLE STEEL COMPANY OF AMERICA
- M42 - VANADIUM-ALLOYS STEEL COMPANY, DIVISION OF VASCO METALS CORPORATION
- M43 - LATROBE STEEL COMPANY
- M44 - BRAEBURN ALLOY STEEL DIVISION, CONTINENTAL COPPER & STEEL INDUSTRIES, INC.

This chart is not to be considered an endorsement of any manufacturer's product or an approved list of any manufacturer's products.

CAST ALLOY TOOL MATERIALS

Nominal Composition

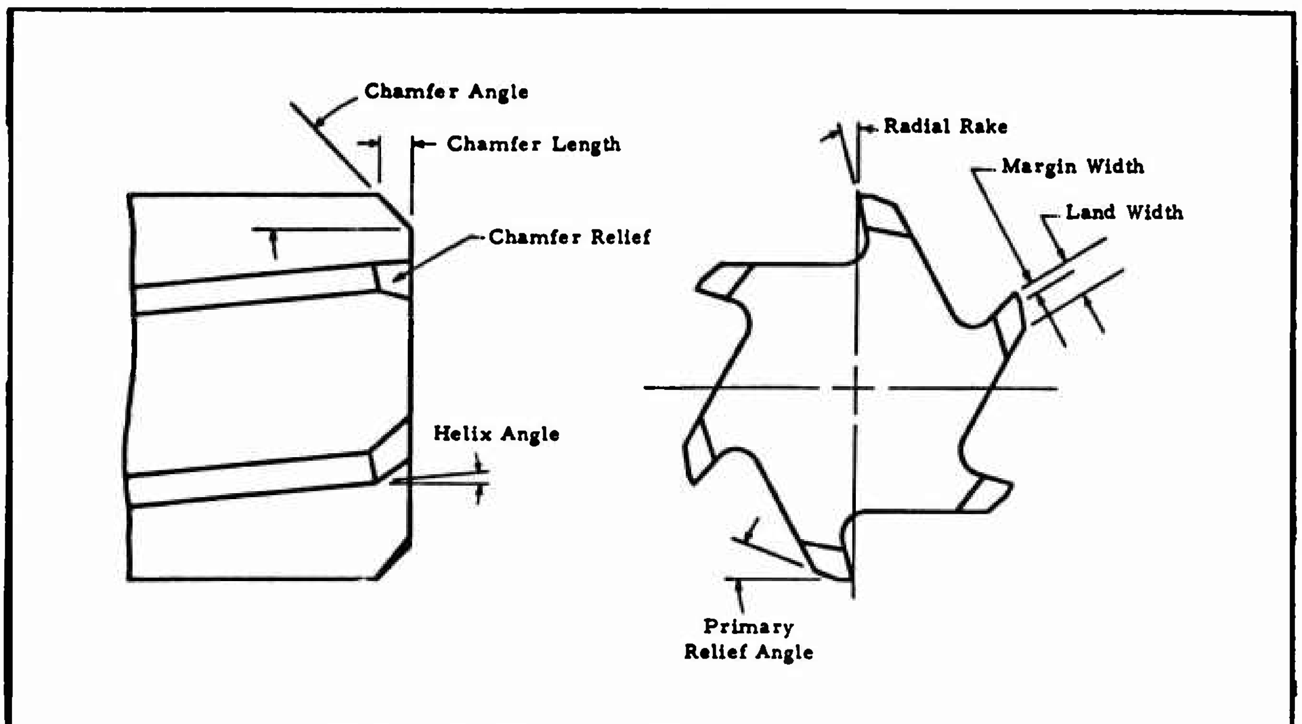
Trade Name	% Co	% Cr	% W	Hardness R_c
Blackalloy 525	44.0	24.0	20.0	63 - 64
Blackalloy T. X. 90	42.0	24.0	22.0	66 - 67
Crobalt #1	48.0	30.0	14.0	59 - 60
Crobalt #2	40.0	33.0	18.0	61 - 62
Crobalt #3	40.0	33.0	20.0	63 - 64
Stellite 98M2	38.0	30.0	18.5	63
Stellite Star J	43.0	32.5	17.5	61
Stellite 3	50.0	31.0	12.5	59
Stellite 19	53.0	31.0	10.5	55
Tantung G	47.0	30.0	15.0	60 - 63
Tantung 144	45.0	28.0	18.0	62 - 64.5

Trade Name	Manufacturer
Blackalloy	Blackalloy Company of America
Crobalt	Crobalt, Inc.
Stellite	Union Carbide Corp., Stellite Division
Tantung	VR/Wesson Company

The procedure used for making cast alloy tools is to melt the particular analysis in an electric furnace and then cast the tools to shape with small stock allowance for finish grinding. The tools are at maximum hardness when removed from the molds and cannot be hot or cold worked and do not respond to heat treatment.

This chart is not to be considered an endorsement of any manufacturer's product or an approved list of any manufacturer's products.

TOOL NOMENCLATURE - Reaming



ROCKWELL-BRINELL - ULTIMATE TENSILE STRENGTH HARDNESS CONVERSION CHART

ROCKWELL C to BRINELL 3000 KG.

For hardened steel and alloys

ROCKWELL C 150 Kg. Load "Brale"	BRINELL 3000 Kg. Load 10 mm Ball
60	614
59	600
58	587
57	573
56	560
55	547
54	534
53	522
52	509
51	496
50	484
49	472
48	460
47	448
46	437
45	426
44	415
42	393
40	372
38	352
36	332
34	313
32	297
30	283
28	270
26	260
24	250
22	240
20	230
-	-

ROCKWELL B to BRINELL 500 and 3000 KG.

For unhardened steel, steel of soft temper, gray and malleable cast iron and most nonferrous metal

ROCKWELL B 100 Kg. Load 1/16" Dia. Ball	BRINELL 500 Kg. Load 10 mm Ball	BRINELL 3000 Kg. Load 10 mm Ball
100	201	240
99	195	234
98	189	228
97	184	222
96	179	216
95	175	210
94	171	205
93	167	200
92	163	195
91	160	190
90	157	185
89	154	180
88	151	176
87	148	172
86	145	169
85	142	165
84	140	162
83	137	159
82	135	156
81	133	153
80	130	150
79	128	147
78	126	144
77	124	141
76	122	139
75	120	137
74	118	135
72	114	130
70	110	125
68	107	121
66	104	117
64	101	114
62	98	110
60	95	107
58	92	104
56	90	101
54	87	-
52	85	-
50	83	-
48	81	-
46	79	
44	78	
42	76	
40	74	
38	73	
36	71	
34	70	
32	68	
30	67	
28	66	
24	64	
20	62	
16	60	
12	58	
8	56	
4	55	
0	53	

BRINELL 3000 KG. TO ULTIMATE TENSILE STRENGTH FOR STEELS

BRINELL 3000 Kg. Load 10 mm Ball	ULTIMATE TENSILE STRENGTH, psi
200	100,000
225	108,000
250	122,000
275	141,000
300	158,000
325	174,000
350	188,000
375	202,000
400	215,000
425	227,000
450	238,000
475	249,000
500	258,000
525	267,000
550	282,000
575	295,000
600	308,000

DEFINITIONS

METALLURGICAL AND HEAT TREATING TERMS

ACICULAR	Alloyed cast irons, which develop high strength on cooling and which have a structure containing martensite mixed with other microconstituents, are termed "acicular," i. e. needlelike.
AGING	A heat treatment of a previously solution heat treated alloy at temperatures which permit solid state precipitation to occur. This treatment usually develops an increase in the hardness and strength of an alloy but may decrease machinability.
ALLOY STEELS	Steels with carbon from 0.1% to 1.1% and containing alloying elements such as nickel, chromium, molybdenum, vanadium, etc. The total of all such alloying elements in these type steels is usually less than 5%.
ALPHA TITANIUM ALLOYS	See Titanium Alloys
ALPHA-BETA TITANIUM ALLOYS	See Titanium Alloys
ANNEALING	A heat treatment of an alloy above its critical or recrystallization temperature, usually followed by furnace cooling. This treatment results in low hardness, high ductility, and usually improves tool life. Some alloys have too high a ductility after annealing and this may lead to poor finish and poor chip control in machining. For such alloys, the cold drawn condition is preferred.
AUSTENITE	A solution of one or more elements in face-centered cubic iron. In most alloy steels, austenite is stable at heat treating temperatures and changes to other constituents such as pearlite, ferrite, martensite, etc. In the austenitic stainless steels, it is stable at room temperature as a result of alloying.
BETA TITANIUM ALLOYS	See Titanium Alloys

BRINELL HARDNESS	A test for determining the hardness of a material by forcing a hard steel or carbide ball of specified diameter into it under a specified load. The result is expressed as the Brinell hardness number, which is the value obtained by dividing the applied load in kilograms by the surface area of the resulting impression in square millimeters. Standard tables are available which indicate the hardness for various size penetrators and indenter loads. The minimum thickness of the test piece should be 1/2". Indenters are spherical, and the load is usually 3000 kg or 500 kg for softer materials.
CARBIDES	Usually refers to the general class of pressed and sintered tungsten carbide cutting tools which contain tungsten carbide plus smaller amounts of titanium and tantalum carbides along with cobalt which acts as a binder. It is also used to describe hard compounds in steels and cast irons.
CARBURIZING	Carburizing heat treatments are used to increase the carbon content at the surface of steels. This is done by placing the parts in contact with carbonaceous solids, liquids, or gases at approximately 1600 to 1700°F. The depth of penetration and amount of carbon pickup are a function of the time, temperature and carburizing medium. Hardening treatments of carburized surfaces develop hardnesses up to 65 R_c.
CASE HARDENING	A heat treating method by which the surface layer of alloys is made substantially harder than the interior. Carburizing and nitriding are common ways of case hardening steels.
CAST STEELS	Steels which are cast to shape and used without having been hot rolled or forged but which are usually heat treated to produce annealed, normalized, or hardened products.
CERAMICS	A term used to describe the general class of hard, brittle and high melting nonmetallic materials such as aluminum oxide, zirconium oxide, beryllium oxide, etc. The same term is also used to designate aluminum oxide and other similar type ceramic cutting tools.

COLD DRAWING	A method of reducing hot rolled rod to size by pulling the rod through a die of the desired diameter. This is frequently done at room temperature but, in any event, must be carried out below the recrystallization temperature of the material. This process often improves machinability by providing better surface finish and chip control.
COLD ROLLING	A method of reducing hot rolled flat stock by passing it between rolls to the desired thickness. Temperature limitations are the same as for cold drawing.
CORROSION RESISTANT STEELS	This is a term often used to describe the cast stainless steels and to differentiate those cast steels used primarily for corrosion applications.
DRAWING	A term often used to mean the same as tempering, which is the preferred designation. "Drawing" should be reserved for hot and cold mechanical working operations.
DUCTILE IRONS	These irons are made by inoculating liquid iron from a cupola with magnesium-nickel or other inoculants to produce microstructures similar to those found in gray iron except that the graphite is in a nodular instead of a flake form. These cast irons are sometimes called "nodular irons."
FERRITE	A solid solution of one or more elements in body-centered cubic iron. It is a common microstructure found in steels and cast irons and generally provides good tool life.
FORGED	A cold or hot mechanical working process performed by presses or hammers and used to shape alloys. Treatments such as annealing or normalizing should generally be applied after forging to improve machinability and uniformity thereof.
GRAY CAST IRONS	Alloys primarily of iron, carbon, and silicon along with other alloying elements in which the graphite is in flake form. These irons are characterized by low ductility but have many other properties such as good castability and good damping capacity.

H	A letter listed along with the composition of aluminum and magnesium alloys indicating that the alloy has been cold worked. H12, H14, etc., are used to indicate various degrees of working.
HARDENING	Designates various heat treatments such as quench hardening, age hardening, and precipitation hardening.
HARDNESS	The ability of a metal to resist penetration. The maximum hardness obtainable in a steel is a function of the carbon content and the heat treatment and is affected only slightly by the alloy content.
HEAT RESISTANT STEELS	Cast steels which are highly alloyed and used for high temperature applications such as furnace conveyor parts, etc.
HIGH SPEED STEELS	Tool steels which contain tungsten, molybdenum, vanadium, cobalt, carbon, and other elements and which are widely used as tools for various machining processes.
HIGH TEMPERATURE ALLOYS	Generally alloys of nickel, cobalt, or iron which are used at temperatures in excess of 1200°F in applications such as rockets, jet engine blades, and compressor and turbine discs, etc.
HOT ROLLED	A term used to describe alloys which are processed through hot rolls. Many alloys are often used in this state and sometimes machinability varies because of differences in cooling conditions from lot to lot.
LEADED ALLOYS	Alloys to which lead has been added to improve machinability.
MALLEABLE	Irons made by malleablizing white cast iron. See Malleablizing.
MALLEABLIZING	Process of annealing brittle white cast iron in such a way that the combined carbon is wholly or partly transformed to graphitic or temper carbon nodules in a ferritic or pearlitic microstructure, thus providing a ductile and machinable material.

MARAGING STEELS	High strength steels of complex composition in which strength is achieved through aging of martensite.
MARTENSITE	An acicular or needlelike microstructure that is formed in quenched steels. It is very hard and brittle in the as quenched form and therefore is usually tempered before being placed into service. The harder forms of tempered martensite have poorer machinability.
NITRIDING	A heat treating method in which nitrogen is diffused into the surface of iron-base alloys. This is done by heating the metal at a temperature of about 950°F in contact with ammonia gas or other suitable nitrogenous materials. The surface, because of formation of nitrides, becomes much harder than the interior. Depth of the nitrided surface is a function of the length of time of exposure and can vary from .0005" to .032" thick. Hardness is generally in the 65 to 70R_c range, and therefore these structures are almost always ground.
NITRIDING STEELS	Steels which are selected because they form good case hardened structures in the nitriding process. In these steels, elements such as aluminum and chromium are important for producing a good case.
NODULAR IRONS	See Ductile Irons.
NORMALIZING	Heat treatment of iron-base alloys above the critical temperature, followed by cooling in still air. This is often done to refine or homogenize the grain structure of castings, forgings, and wrought steel products.
O	A letter listed along with the composition of aluminum and magnesium alloys indicating that the alloy has been annealed.
OHFC	A designation applied to indicate oxygen free, high conductivity copper.
PEARLITE	A microconstituent found in iron-base alloys consisting of a lamellar (platelike) composite of ferrite and iron carbide. This structure results from the decomposition of austenite and is very common in cast irons and annealed steels.

PLAIN CARBON STEELS	Steels with carbon plus small amounts of manganese, silicon, sulfur, phosphorus, or other elements.
PRECIPITATION HARDENING STAINLESS STEELS	Certain stainless steel compositions which respond to precipitation hardening or aging treatment.
PRESSED	The "as pressed" condition of alloys when compacted from powders. Pressing of powdered metals is generally followed by sintering. Some difficult or impossible to machine materials such as tungsten and carbides are shaped by various machining operations in the "green" condition, generally produced by low temperature presintering.
QUENCHED	Alloys which are rapidly cooled by immersion in liquids or gases after heating.
REFRACTORY ALLOYS	Alloys or elements which have melting temperatures above 4000° F. The most common refractory alloys of current industrial interest are tungsten, molybdenum, columbium, and tantalum.
RESULFURIZED ALLOYS	Alloys which have sulfur added to improve machinability.
ROCKWELL HARDNESS	Rockwell hardness is a measure of the difference in depth of penetration of an indenter between a major and a minor load. Normally a minor load of 10 kilograms is applied, followed by the application and release of a major load which will vary from 60 to 150 kilograms. A direct reading dial indicates the increase in penetration caused by the application of the major load. This dial has various scales for use with the various major loads and penetrators. The more commonly used Rockwell scales are Rockwell "C" (R_C), using a diamond Brale penetrator and a 150 kilogram major load, and Rockwell "B" (R_B), using a 1/16" diameter ball penetrator and a major load of 100 kilograms. Other scales used in this data book are R_A, R_E, R_R, and R_M.

SINTERED	The sintered condition results from a heating of pressed powdered metals for specified times at elevated temperature. Improved strength and other benefits result, but generally machinability is decreased.
SOLUTION TREATED	A process in which it is possible to dissolve microconstituents by taking certain alloys to an elevated temperature and then keeping them in solution after quenching. Often a solution treatment is followed by a precipitation or aging treatment to improve the mechanical properties. Most high temperature alloys which are solution treated and aged machine better in the solution treated state just before they are aged.
STAINLESS STEELS	Steels which have good or excellent corrosion resistance. One of the common grades contains 18% chromium and 8% nickel. There are three broad classes of stainless steels -- ferritic, austenitic, and martensitic. These various classes are produced through the use of various alloying elements in differing quantities.
STRESS RELIEVED	The heat treatment used to relieve the internal stresses induced by forming or heat treating operations. It consists of heating a part uniformly, followed by cooling slow enough so as not to reintroduce stresses. To obtain low stress levels in steels and cast irons, temperatures as high as 1250°F may be required.
T	A letter listed along with the composition of aluminum and magnesium alloys indicating that the alloy has been subjected to heat treatment. T4, T5, T6, etc. indicate various specific heat treatments.
TH	Letters used with the composition of precipitation hardening stainless steels designating special heat treatments using in part a refrigeration cycle to develop specific properties.

TEMPERED	Reheating of hardened steels or hardened cast irons to reduce hardness and to lower internal stress. The temperature used depends upon the mechanical properties specified but generally ranges from 300 to 1200°F.
THERMOPLASTIC	A plastic which can be repeatedly softened by an increase in temperature and hardened by a decrease in temperature. Heating causes physical changes rather than chemical.
THERMOSETTING PLASTIC	A plastic which upon heating is changed chemically into a material having new properties.
TITANIUM ALLOYS	Alloys of the element titanium. They combine light weight, excellent strength, moderately good high temperature strength, and excellent corrosion resistance. Various alloying elements and heat treatments provide differing crystal structures. Depending upon the crystal structure of the finished alloy, they are classified as alpha, beta, or alpha-beta alloys.
TITANIUM CARBIDE	Carbides in which the greatest amount of carbide is titanium instead of tungsten and which also contain other carbides plus nickel and molybdenum as binders.
TOOL STEELS	Steels used to make tools of all types and dies. Many of these steels have considerable quantities of alloying elements such as chromium, carbon, tungsten, molybdenum, and other elements. These form hard carbides which provide good wearing qualities but at the same time decrease machinability. Tool steels in the trade are classified for the most part by their applications, such as hot work die, cold work die, high speed, shock resisting, and mold steels.
ULTIMATE STRENGTH	The maximum stress, expressed in pounds per square inch, which a material will carry before breaking under a slowly applied, continually increasing load.

ULTRA HIGH STRENGTH STEELS	Those steels intended for designs requiring great strength (generally greater than 200, 000 psi) such as landing gears, rocket motor cases, etc. This class includes some of the alloy steels and tool steels heat treated to high hardness as well as the hardened maraging steels.
WROUGHT	To indicate alloys which have been mechanically worked in their manufacture in contrast with the cast condition.
YIELD STRENGTH	Yield strength is the stress obtained in a tensile or compressive test of materials. At this stress, materials begin to take a permanent set, i. e. they will not return to their original shape after a load is removed.

DESCRIPTION OF AFMDC

AIR FORCE MACHINABILITY DATA CENTER, 3980 Rosslyn Drive, Cincinnati, Ohio 45209. Operated for the Air Force Materials Laboratory, Manufacturing Technology Division, under Contract AF 33(615)-5282, by Metcut Research Associates Inc.

SCOPE

The Air Force Machinability Data Center (AFMDC) collects, evaluates, stores, and disseminates material removal information including specific and detailed machining data for the benefit of industry and government. Strong emphasis is given to engineering evaluation for the purpose of developing optimized material removal parameters, such as speeds, feeds, depths of cut, tool material and geometry, cutting fluids and other significant variables. Data are being processed for all types of materials and for all kinds of material removal operations such as turning, milling, drilling, tapping, grinding, electrical discharge machining, electrochemical machining, etc.

COLLECTION

AFMDC has a mechanized system in which punch cards are used to store and retrieve all types of material removal information including all significant numerical data. An IBM 1130 computing system is being used for storing and processing data from a master card and disk file and for computer decoding. The focal concept for acquisition, interrogation, or presentation of information is the specific material *(with definite chemical, physical, or mechanical properties)* and the specific material removal operation being used. When necessary, card source control codes may be used to retrieve original documents which are in document storage at AFMDC.

INFORMATION SERVICES

AFMDC places strong emphasis on providing specific and detailed answers to technical inquiries in the field of material removal. A User File, consisting of important users in the field of material removal, has been developed to receive information products including machining data pamphlets and tables on materials of current interest, state-of-the-art reports, technical announcements, and other appropriate items. Services are available without charge to the aerospace industry, Department of Defense *(including all of the military services and their contractors)*, and other government agencies, technical institutions, and non-military industries in a position to assist the defense effort.

TO REQUEST MACHINING INFORMATION . . . .

TELEPHONE:	513-271-9510
TWX:	810-461-2840 *or*
WRITE:	Air Force Machinability Data Center 3980 Rosslyn Drive Cincinnati, Ohio 45209

TO HELP US ANSWER YOUR INQUIRY, IF POSSIBLE PLEASE:

1. Identify the material being machined *(specification or trade name)*; condition *(as cast, hot rolled, cold drawn, annealed, quenched and tempered, etc.)*; microstructure and hardness.
2. Identify the material removal operation in question *(turning, milling, drilling, tapping, surface grinding, electrical discharge machining (EDM), electrochemical machining (ECM), etc.)*.
3. Specify reasons for requiring data unless your needs are proprietary. This enables AFMDC to broaden the scope of its technical advice.
4. Specify delivery requirements.
5. Indicate to whom the inquiry reply should be sent.
6. Transmit all details concerning present practices, including feeds, speeds, cutting tool material and geometry, cutting fluids, etc., in the event your inquiry pertains to improvement of an existing machining situation.

* * * *

NOTE: *Association of the names of companies and individuals with specific requests is kept confidential. However, data developed remain the property of AFMDC for dissemination as required for answering similar inquiries and for developing data products.*

OTHER SOURCES OF MACHINING DATA*

1. AIR FORCE MACHINABILITY DATA CENTER. See Page A-17 for a complete description of services available.

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*Partial list of important sources in addition to those listed on Page vi from which machining data were extracted for this report.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Manufacturing Technology Division Air Force Materials Laboratory Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

This report presents an extensive set of machining data selected from six USAF Machinability Reports. Data are tabulated and arranged in formats including machining variables such as tool material, tool geometry, cutting fluid, depth, feed, and tool life end point. For each of the data lines, the relationship between tool life and cutting speed is expressed in at least three sets of data, thereby making it possible to optimize for maximum production or minimum cost. While these data are expected to be of considerable assistance in providing data for numerical control applications, they are also of great value in any type of machining situation involving the materials for which machining data are presented. Specifically this report, the last of a series, pertains to reaming.

The previous reports in this series were issued separately as: Turning, Face Milling, Drilling, Peripheral End Milling, End Mill Slotting, and Tapping (Report Nos. AFMDC 66-1.1 through 66-1.6). All reports will be collected in a single volume (Report No. AFMDC 66-1).

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Reaming						
Numerical Control						
Machining Data						
Tool Life Data						
Alloy Steels						
Stainless Steels						
Titanium Alloys						
High Temperature Alloys						
Refractory Alloys						
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